

## **Attachment 10**

### **The Sand Wash Basin**

The Sand Wash Basin is located in northwestern Colorado and southwestern Wyoming. It is part of the Greater Green River Basin that also includes the Washakie Basin, the Great Divide (Red Desert) Basin, and the Green River Basin (Figure A10-1). These sub-basins are separated by uplifts caused by deformation of the basement rock. The Cherokee Arch, an anticlinal ridge that runs east to west along the Colorado-Wyoming border, separates the Sand Wash Basin from the adjacent Washakie Basin. The Greater Green River Basin, in total, covers an area of approximately 21,000 square miles. The Sand Wash Basin covers approximately 5,600 square miles, primarily in Moffat and Routt Counties of Colorado. There appears to be no commercial production at present (GTI website, 2002).

#### **10.1 Basin Geology**

The geologic history of the Sand Wash Basin is relatively complex, characterized by periods of deposition followed by deformation related to tectonic activity. This activity has impacted depositional patterns, coal occurrence and maturity, and hydrology (Tyler and Tremain, 1994). A very thorough discussion of the geologic history of the Sand Wash Basin is available in Tyler and Tremain (1994).

The coal bearing formations in the region include the Iles, Williams Fork, Fort Union, and the Wasatch Formations (Figure A10-2). These formations were deposited, from bottom to top, during the Upper Cretaceous, Paleocene and upper Paleocene periods. The total thickness of the coal seams encountered in these formations can be up to 150 feet (Quarterly Review, 1993). Basement rock formations in the Sand Wash Basin can be as deep as 17,000 feet (Tyler and Tremain, 1994). A map of the coal and geologic features is presented in Figure A10-3a and a conceptual cross-section is presented in Figure A10-3b.

The Sand Wash Basin was near the western edge of the Western Interior Seaway that spread across what is now central North America during the Upper Cretaceous (Figure A10-4). During the late Cretaceous the seaway retreated to the northeast. Intermontane basins developed during the Laramide, and coal-bearing fluvial-lacustrine sediments were deposited (Quarterly Review, 1993). The coal in the Sand Wash Basin was formed from peat deposited in swamps along a broad coastal plain. Sediments that eroded from nearby uplift formations covered the peat beds (Tyler and Tremain, 1994). The alternating deposition of organic material and sands was repeated many times creating layers of coal interbedded with layers of sandstone and other sedimentary rocks that filled the basin.

Cretaceous or Mesaverde Group coal in the Sand Wash Basin ranges in rank from sub-bituminous along the basin margins to high volatile A bituminous coal in the deeper parts of the basin. These ranks are indicative of moderately mature to well developed mature coal formed under high pressure and high heat. Within the Mesaverde Group, the most important potential coalbed methane resource in the basin (Kaiser et al., 1993), the coal ranks from sub-bituminous along the basin margins to medium volatile bituminous in the basin center (Kaiser

et al., 1993). The methane in these coals formed both biogenically (by bacterial action on organic matter), and thermogenically (under high temperature). The average gas content of 261 coal samples collected during two studies was 147 standard cubic feet of methane per ton of coal (Boreck et al., 1977 and Tremain and Toomey, 1983). Some samples from the Sand Wash Basin have been found to contain as much as 540 standard cubic feet of methane feet per ton. Gas content has generally been found to increase somewhat with depth. At depths of less than 1,000 feet, gas content is typically less than 20 standard cubic feet per ton, which has been taken to indicate that gas probably leaked out of the shallow coalbeds into the atmosphere. Analysis of gas samples has indicated that the gas is typically 90% methane, the remainder being mostly nitrogen and carbon dioxide (Scott, 1994). Carbon dioxide content ranges from 1 to more than 25 percent (Scott, 1994).

Of all the coal-bearing formations, the Upper Cretaceous Williams Fork is the most significant unit because it contains the thickest and most extensive coal beds. The Williams Fork Formation is within the Mesaverde Group that also includes the Almond Formation along the Wyoming state line (Tyler and Tremain, 1994). The Almond Formation is shown (Figure A10-2) as a separate formation overlying the Williams Fork (Tyler and Tremain, 1994), but is also reported (Kaiser, et al, 1993) to be a lateral equivalent of the upper Williams Fork Formation found in the southern Sand Wash basin. For more information relative to this apparent conflict see Kaiser, et al. (1993, p. 29). The coal-bearing Williams Fork Formation outcrops along the southern and eastern margins of the basin, and may be deeper than 8,000 feet in the deepest part of the basin (Figure A10-3b). The coals are interbedded with sandstones and shale. The thickest total coal deposits in the Williams Fork Formation, up to 129 feet, are centered near Craig, Colorado. This total is made up of several separate coal beds up to 25 feet thick interbedded with sedimentary rock.

Stratigraphically above the Williams Fork Formation, the Paleocene Fort Union Formation, which includes sandstone, siltstone, shale, and coal, is also a potentially productive zone for coalbed methane production. The Fort Union outcrops at the Elkhead Mountains east of the basin and along the southern and western parts of the basin. The bottom of the Fort Union Formation is about 7,000 feet below the surface. Net coal thickness can be up to 80 feet with as many as nine individual beds. Individual beds up to 50 feet thick have been identified.

The Wasatch Formation includes beds of shale and sandstone and minor amounts of coal. It can extend as deep as 2,000 feet below the surface. The Wasatch Formation has not been targeted for coalbed methane development because of the small quantity of coal.

## **10.2 Basin Hydrology and USDW Identification**

Regional ground water flow in the Sand Wash Basin is from east to west and to the northwest towards the center of the basin. Water enters the aquifers at the exposed outcrops along the southern and eastern margins of the basin and moves northwestward. Vertical movement of ground water, including potential artesian conditions, is dependent on local geologic conditions. Kaiser and Scott (1994) summarize their extensive investigation of ground water movement within the Fort Union and Mesaverde group. The Mesaverde group is a highly transmissive aquifer. The coal beds along with associated sandstone beds within the group

may be the most permeable part of the aquifer. The Williams Fork Formation contains sandstone beds that are reported to be excellent aquifers (Brownfield, personal communication, 2002). Lateral flow within the Fort Union Formation is slower, in part, owing to less permeable fluvial sandstones in the unit.

Dissolved solids concentrations of ground water in the Mesaverde Group were investigated by Kaiser and Scott (1994) (Figure A10-5). They found that chloride concentrations ranged from 290 mg/L in the eastern area of the basin near the outcrops where water enters the aquifers, to more than 26,000 mg/L in the central part of the basin. Calcium showed a similar pattern of distribution with the lowest concentrations near the outcrops, increasing toward the basin center. Calcium concentrations ranged from 10 mg/L to over 2900 mg/L. Based on the chloride and calcium concentrations presented by Kaiser and Scott (1994), the water in the aquifers near the recharge areas at the basin margins meets the water quality criteria for a USDW, but the water in the deeper central part of the basin does not (Figure A10-5). The mapped outcrop area (Figure A10-3a) of the Mesaverde Group indicates that the coal is itself a USDW where it is relatively shallow and close to the eastern and southern margins of the basin.

### 10.3 Coalbed Methane Production Activity

Coalbed methane resources in the Sand Wash Basin have been estimated at 101 trillion cubic feet (TCF). Approximately 90% of this resource is within the Williams Fork Formation (Kaiser et al., 1993). Approximately 24 TCF of coalbed methane are located at depths less than 6,000 feet below grade (Kaiser et al., 1994). Despite this ample resource, economic viability of recovery of the gas is limited by the presence of large volumes of water in most coal beds. Exploration in the 1980s and 1990s led to limited commercial use of the resource. Records from the Colorado Oil and Gas Commission indicate that approximately 31 million cubic feet of coalbed methane was produced in Moffat County during 1995 (Colorado Oil and Gas Commission web site, 2001). From 1996 to 1999 (the last year that data are available), no further gas was produced in this County (Colorado Oil and Gas Commission web site, 2001). However, Colorado Oil and Gas Commission records indicate that approximately 120 permits for drilling within Moffat County were issued during the period from February 2000 through August 2001 (Colorado Oil and Gas Commission web site, 2001). It is not clear exactly how many of these permits were related to coalbed methane exploration and production, but a handful of the permits were issued to gas companies, and the permits are listed as targeting known coal beds within specific methane producing formations (Colorado Oil and Gas Commission web site, 2001).

At Craig Dome in Moffat County, Cockrell Oil Corporation drilled a 16-well development for exploration in the Williams Fork Formation. The wells were abandoned a short time later because of excessive water. An average total of 40 feet of high-volatile bituminous coal was encountered in beds up to 15 feet thick. Gas content was tested at 10 to 350 cubic feet per ton of coal. Wells were cased through the target coal bed, perforated, and hydraulically fractured using water and sand. The wells yielded large volumes of fresh water with TDS <1,000 mg/L, but little gas (Colorado Oil and Gas Commission web site, 2001). Water was removed at an average of 21,756 gallons per day per well during testing. Based on records from the

Colorado Oil and Gas Commission, Cockrell Oil Corp does not appear to be involved currently with coalbed methane production in this region (Colorado Oil and Gas Commission web site, 2001).

Limited commercial success has been experienced in the basin. As of 1993, only one commercial operator, Fuelco, was working in the basin. Fuelco was operating 11 wells along Cherokee Arch at 40-80 acre spacing. Well depths were to 2,500 feet. A total of 40 feet of coal was found in the Almond Formation (Mesaverde Group) between 810 to 2,360 feet. All wells were cased through the coal, selectively perforated, and stimulated using water and sand. Gas production averaged a total of 50 thousand cubic feet per day from four wells. The best well peaked at 100 thousand cubic feet per day (Quarterly Review, 1993). Total production of gas through 1993 from the Dixon Field, the only producing field in this region, was about 84 million cubic feet (Kaiser et al., 1993). Total water production for the four wells was high at 126,000 gallons per day due to the high permeability of the coal (Quarterly Review, 1993). Water pumped from the wells contained 1,800 mg/L of TDS and was discharged to the ground with a NPDES permit (Quarterly Review, 1993).

The Sand Wash Basin has been used by the University of Texas Bureau of Economic Geology in the development of its Coalbed Methane Producibility Model (Kaiser et al., 1994). The development of the model was based on a comparison of basins that included the Sand Wash Basin and the San Juan Basin of southwestern Colorado and northwestern New Mexico. The San Juan Basin has proven to be a very productive coalbed methane resource. The Sand Wash Basin was used as an example of a low potential productivity basin (Figure A10-6) (Kaiser et al., 1994).

Hydraulic fracturing has been used in the Sand Wash Basin to improve the flow of gas into the wells. Hydraulic fracturing fluids have typically consisted of water with sand used as a proppant. However, very little information was available regarding specific types and volumes of fluids and proppants used. No indication of the use of other materials was noted in the sources reviewed (Colorado Oil and Gas Commission web site, 2001).

#### **10.4 Summary**

Coal beds containing methane gas are present within the Sand Wash Basin at accessible depths. Some investigation and very limited commercial development of this resource have occurred, mostly in the late 1980s and early 1990s. There appears to be no commercial production at present. Development of coalbed methane resources in the Sand Wash Basin has been slower than in many other areas due to limited economic viability. The need for extensive dewatering in most wells has been a limiting factor, compounded by relatively low gas recovery.

Between 1996 and 1999, no coalbed methane has been produced in Moffat County. Permits for new gas wells have been issued indicating that there may be some continued interest in this area (Colorado GIS, 2001).

Ground water quality in the basin varies greatly. Typically, chloride and calcium concentrations within the coal-bearing Mesaverde Group are low and potentially within potable ranges in the eastern and southern parts of the basin, implying the existence of a USDW, and therefore the potential for impacts. Concentrations increase as the water migrates toward the central and western margins of the basin. Concentrations have been detected in the western portion of the Basin at levels significantly higher than USDW water quality standards.

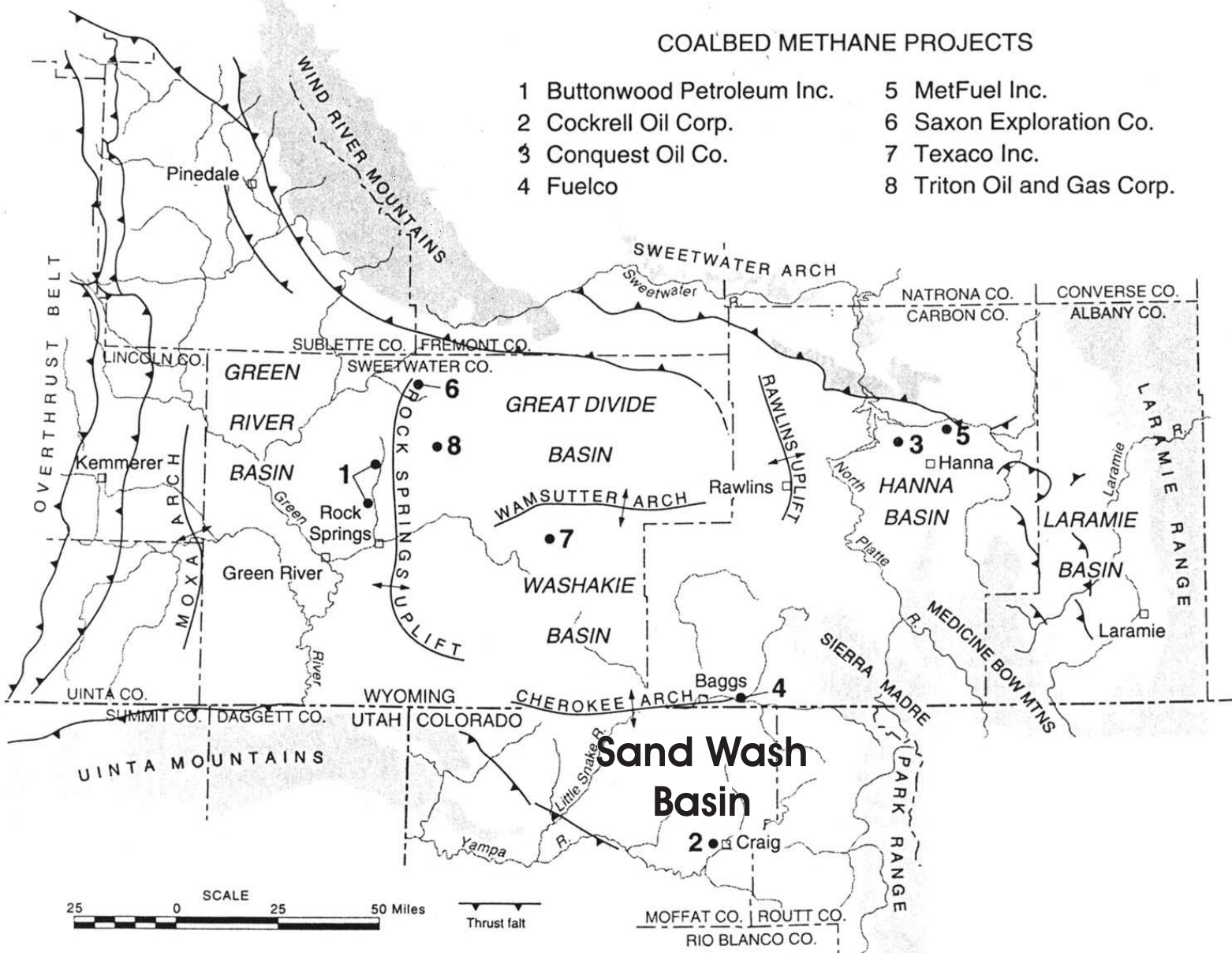
Compared to other potentially productive areas of the country, very little information has been published regarding current developments, ground water location and conditions, drilling techniques, etc. The level of information available seems to be commensurate with the amount of commercial activity.

The use of fracturing fluids, specifically water and sand proppant, has been reported for this basin. No record of any other fluid types has been noted. Although variable, the water quality within the fractured coals indicates the presence of USDWs within the coal beds. More data need to be gathered in order to make more definitive conclusions about USDW contamination pathways. However, it is clear that USDWs and coal beds are linked in this basin and that hydraulic fracturing is viewed as an essential practice for enhancing well production in the basin.

---

**REFERENCES**

- Brownfield, Michael. 2002. USGS, Denver Federal Center, Denver, CO. personal (written) communication.
- Boreck, D. L., Jones, D. C., Murray, D. K., Schultz, J. E., and Suek, D. C., 1977, Colorado coal analyses, 1975 (analyses of 64 samples collected in 1975): Colorado Geological Survey Information series 7, 112 p.
- Colorado Oil and Gas Commission Website-Colorado GIS. 2001. Approved Drilling Permits <http://cogccweb.state.co.us/cogis/DrillingPermitsList.asp>
- Gas Technology Institute (GTI) website, 2002. Drilling and Production Statistics for Major US Coalbed Methane and Gas Shale Reservoirs. <http://www.gastechnology.org>
- Kaiser, W. R., Scott, A. R., Hamilton, D. S., Tyler, Roger, McMurry, R. G., Zhou, Naijiang, and Tremain, C. M., 1993, Geologic and hydrologic controls on coalbed methane: Sand Wash Basin, Colorado and Wyoming: The University of Texas at Austin, Bureau of Economic Geology, topical report prepared for the Gas Research Institute under contract no. 5091-214-2261, GRI-92/0420, 151p.
- Kaiser, W.R. and Scott, A.R. 1994. Hydrologic setting of the Fort Union Formation, Sand Wash Basin. Report of Investigations – Geologic and Hydrologic Controls on Coalbed Methane, Texas, University, Bureau of Economic Geology, 220, pp. 115-125.
- Kaiser, W.R., Scott, A., Zhou, N., Hamilton, D.S., and Tyler, R. 1994. Resources and Producibility of Coalbed Methane in the Sand Wash Basin. Report of Investigations – Geologic and Hydrologic Controls on Coalbed Methane, Texas University, Bureau of Economic Geology, 220, pp. 129-145.
- Quarterly Review of Methane From Coal Seams Technology 1993. Greater Green River Coal Region Wyoming and Colorado, pp. 13-17
- Scott, Andrew R. 1994. Coal Rank, Gas Content, and Composition and Origin of Coalbed Gases, Mesaverde Group, Sand Wash Basin. Bureau of Economic Geology and Colorado Geological Survey, Resource Series 30, pp. 51-62.
- Tremain, C. M., and Toomey, J., 1983, Coalbed methane desorption data: Colorado Geological Survey Open-file Report 81-4, 514 p.
- Tyler, Roger, and Tremain, C.M. 1994. Tectonic evolution, stratigraphic setting, and coal fracture patterns of the Sand Wash Basin. Report of Investigations – Geologic and Hydrologic Controls on Coalbed Methane, Texas University, Bureau of Economic Geology, 220, pp. 3-19.



Location of the Sand Wash Basin of Colorado and Wyoming (Quarterly Review, 1993)



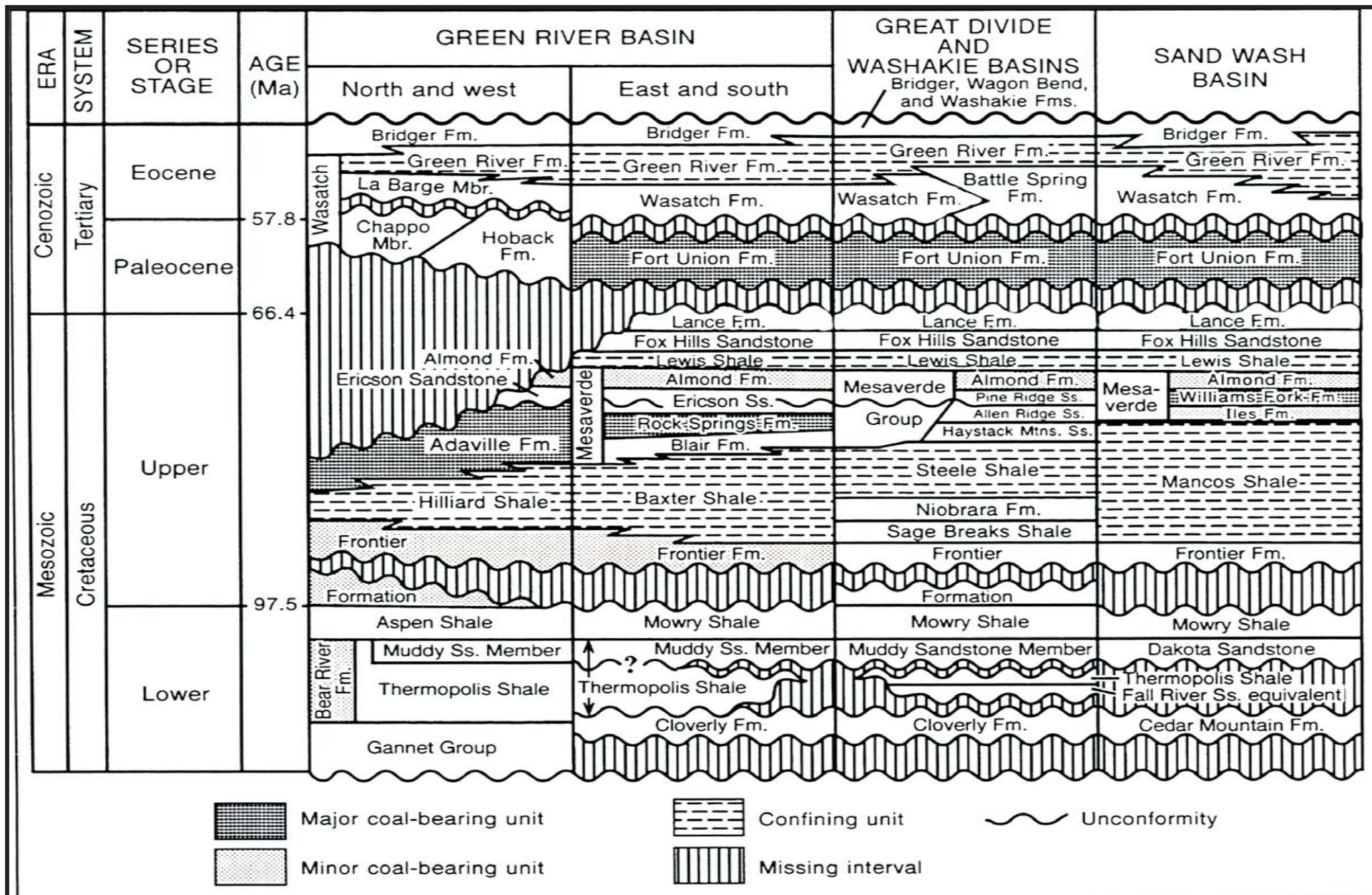
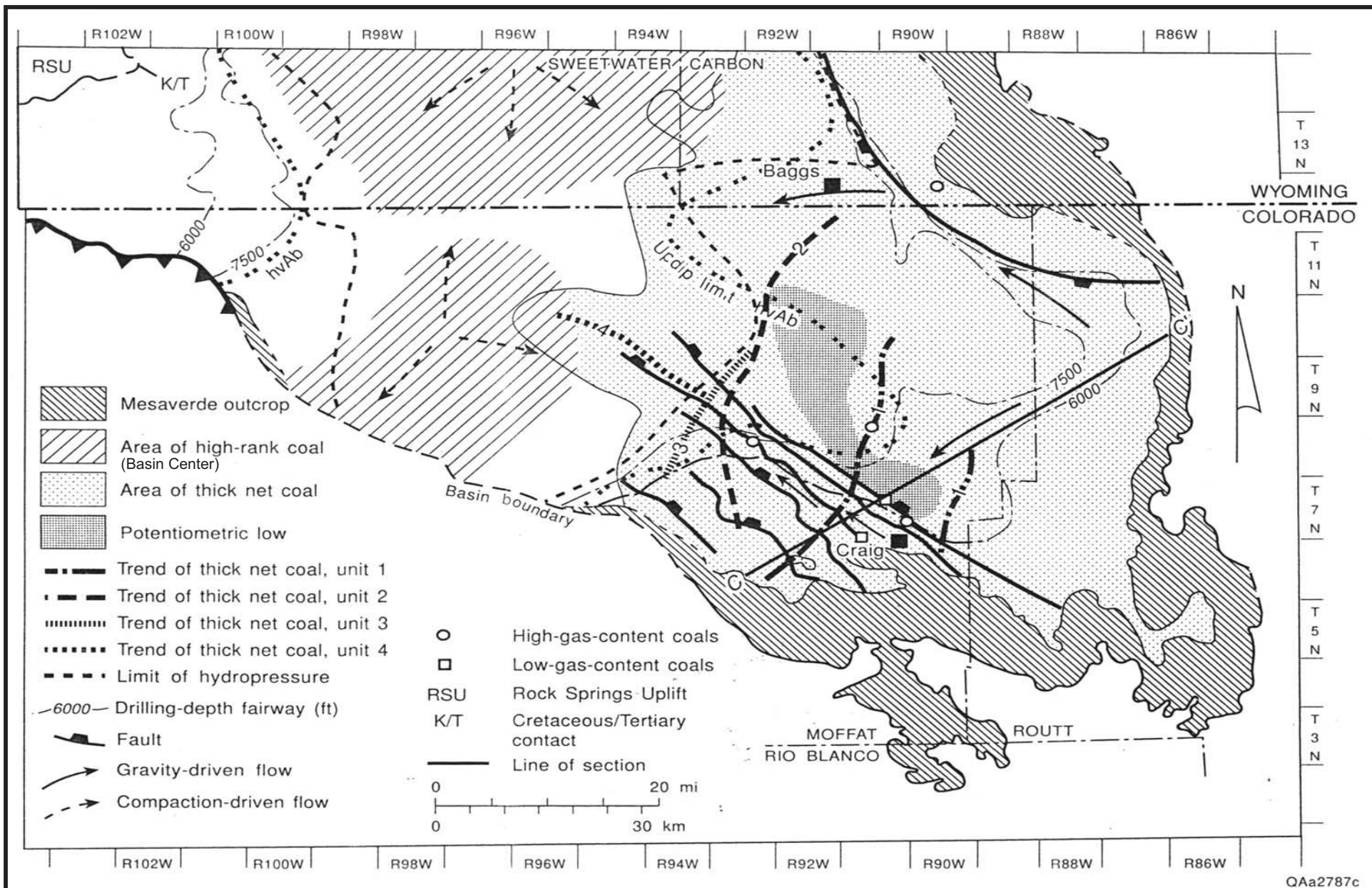


Diagram of Geologic Formations Within the Sand Wash Basin and Neighboring Basins  
(adapted from Tyler and Tremain, 1994)

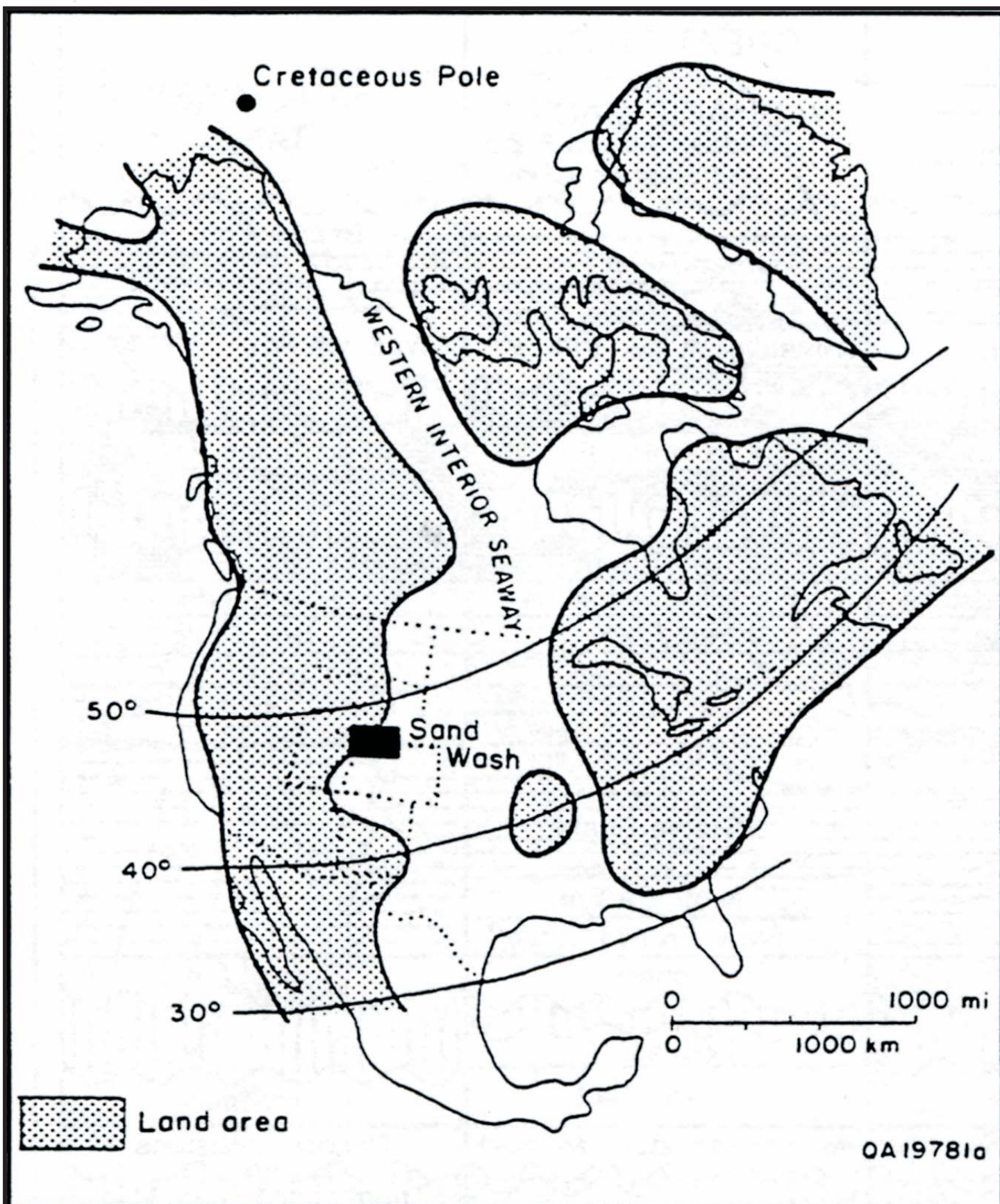




Map of Coal and Geologic Features Within the Sand Wash Basin (Tyler and Tremain, 1997)

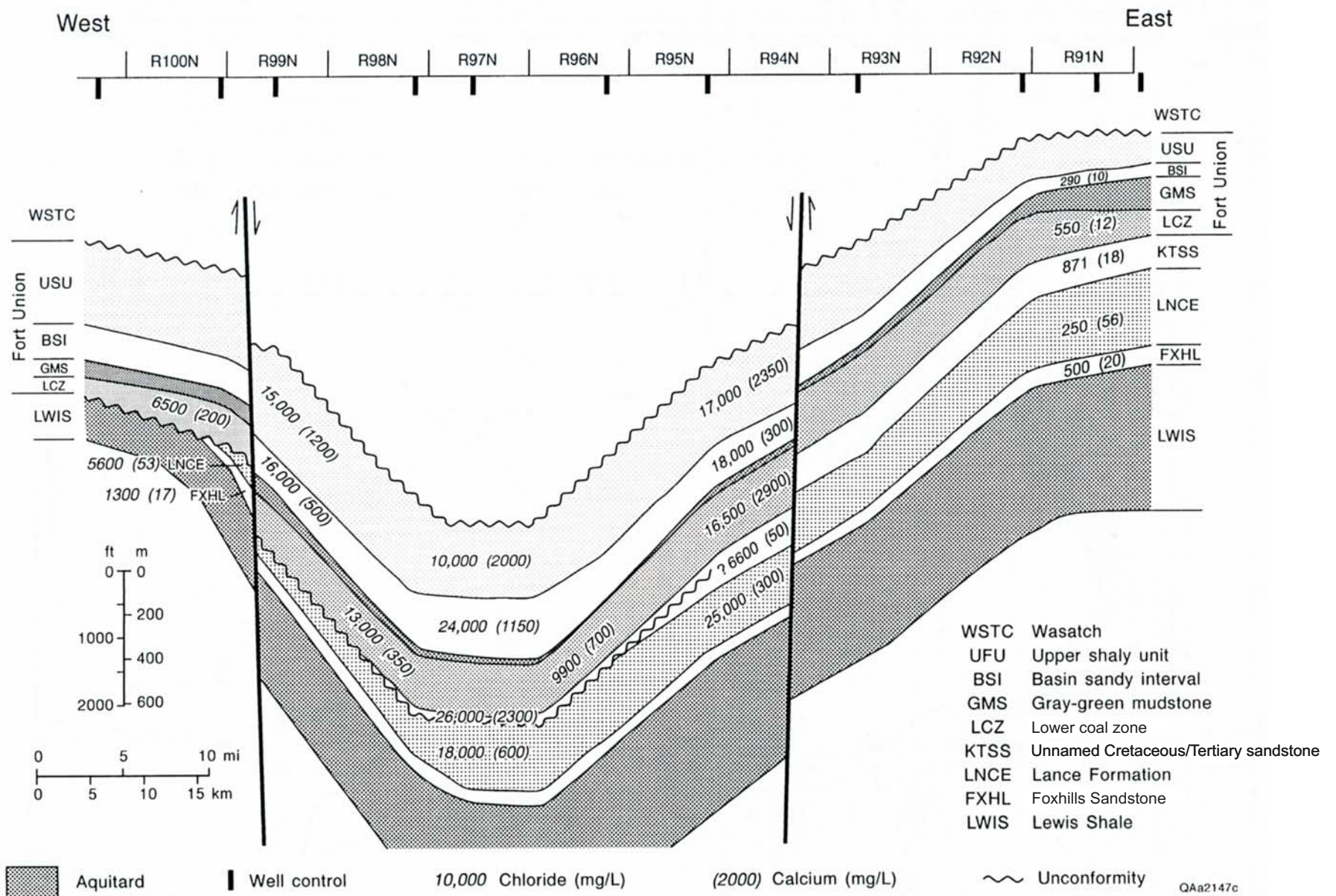






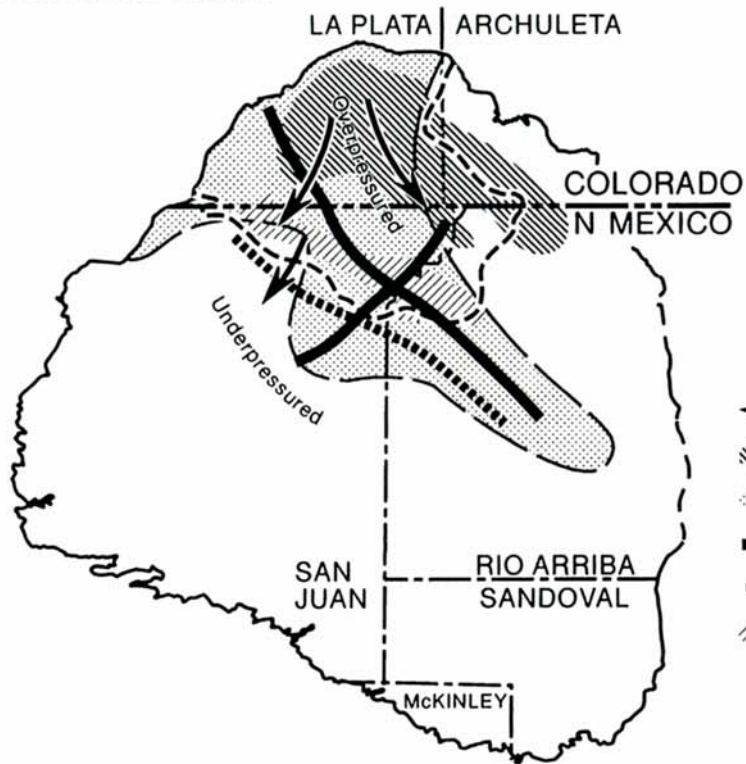
Location of the Sand Wash Basin in Relation to the Western Interior Seaway of Upper Cretaceous Times (Tyler and Tremain, 1994)



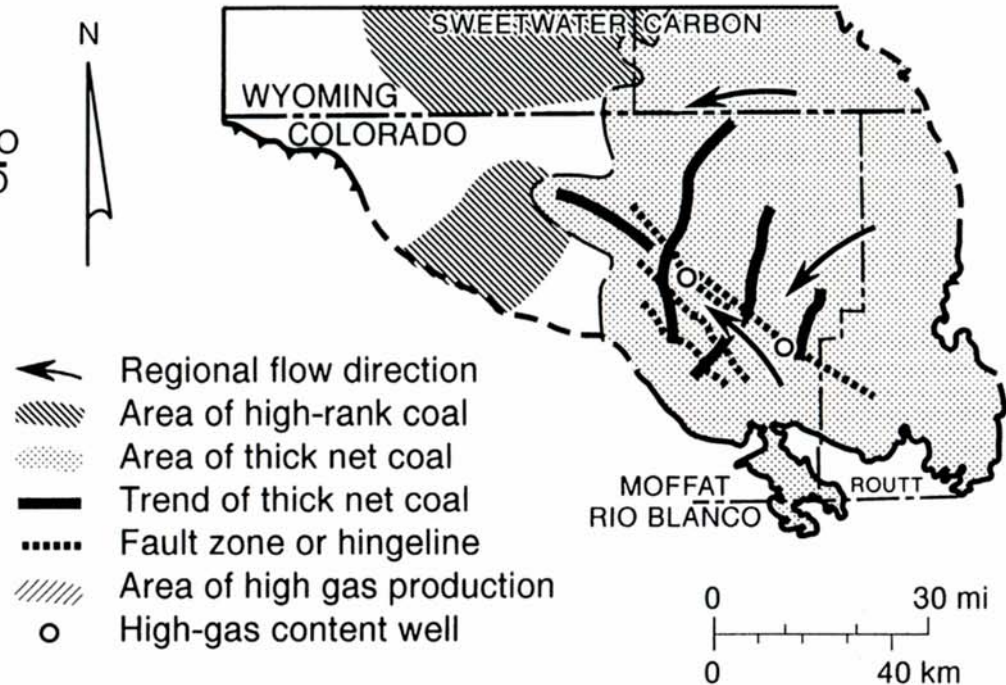


Ground Water Quality Trends in the Sand Wash Basin (Scott, 1994)

(a)  
San Juan Basin



(b)  
Sand Wash Basin



Comparison of Features Relevant to Coalbed Methane Production - San Juan Basin and Sand Wash Basin  
(Kaiser et al., 1994)